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Research Note INT-401

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Susceptibility of Lodgepole Pine to Western Gall Rust Within the Middle Columbia River System

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Abstract—Seedlings from 107 populations of lodgepole pine were inoculated at the beginning of their second year's growth. The overall infection level was 87 percent. Populations varied from 45 to 100 percent infected. Variation for geographic area and elevation was random. The average number of galls was 3.28, and this varied from 0.72 to 6.33. The most susceptible populations were from the northeastern (northwestern Montana) and the southern (southern Idaho) portions of the area sampled. Three major categories of resistance were evident: (1) trees that expressed no symptoms—8 percent; (2) trees that expressed stem reactions—4 percent; and (3) trees in which the galls died—1 percent.

Keywords: disease resistance, *Endocronartium harknessii, Pinus contorta*

Western gall rust—caused by *Endocronartium harknessii* (J. P. Moore) Y. Hiratsuka—is a common stem rust throughout the range of lodgepole pine (*Pinus contorta* L.). The damage varies with region, size of tree, and climatic conditions (Dahms 1965; Peterson 1971; Powell and Hiratsuka 1973), but the rust is considered a major disease (Hiratsuka and Powell 1976) in most areas, especially in plantations (Martinsson 1980; Powell and Hiratsuka 1973).

Lodgepole pine in the Inland Empire—a large area encompassing northeastern Washington, Idaho north of the Salmon River, and western Montana—are severely damaged by western gall rust (Peterson 1961). Recently, tree improvement programs have been started with the objective of taking advantage of the fast early growth rate of lodgepole pine. Knowledge of the variability of gall rust susceptibility within the region is unknown. The task of tree improvement programs is creation of a breeding population. Therefore, it is imperative that, prior to the establishment of the breeding population, information is made available concerning the pattern of susceptibility to its major pest problem. Martinsson (1980) reported that high-elevation and high-latitude provenances of British Columbia were more susceptible to western gall rust. Yanchuk and others (1988) repeated this study when the trees were older, and with several more provenances, and found the same relationship with elevation. However, they reported that the coastal provenances were most susceptible. The data for these tests were from a test site that was naturally infected by western gall rust.

The objective of this study was to assess the susceptibility of lodgepole pine to western gall rust over the Inland Empire by using artificial inoculation of many seed sources.

MATERIALS AND METHODS

Seeds used in this test were from 107 populations (stands) within Idaho, northeastern Washington, and western Montana west of the Continental Divide, and covering the elevation range of the species (fig. 1). Most stands were represented by an equal volume of seed from 10 randomly selected trees. The seeds were sown in 52-cm^3 containers. Seedlings were grown and overwintered in a shadehouse at the Forestry Sciences Laboratory at Moscow, ID (lat. 46°43' N., long. 117°00' W., elevation 801 m). The seedlings were watered and lightly fertilized, with the objective of producing seedlings that were not stressed but without accelerating their growth.

The experimental design was:

- 107 populations
- 10 seedlings per population per replication, in population plots
- 3 replications, resulting in a total of 3,110 seedlings in the test

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Figure 1—Number and locations of populations of lodgepole pine that were included in this test. Letters A to D locate geographic zones used in analyses.

Prior to inoculation, the seedlings were randomized into the experimental design. In May the seedlings were moved into a mist chamber in preparation for inoculation. The seedlings were starting their second growing season, and about 10 mm of the needle tips had emerged from the fascicle sheaths. Mist nozzles were used to provide a constant visible fog throughout the chamber. Twenty-four hours later, the seedlings were thoroughly saturated and allowed to set for 1 hour to drain excess moisture from the stems of the trees. The seedlings were then inoculated.

The seedlings were ready to inoculate before aeciospores were produced in nature, and therefore stored aeciospores had to be used. The aeciospore collection was from lodgepole pine near the Moose Creek Reservoir (lat. 46°52' N., long. 116°24' W., elevation 879 m). The aeciospores were collected from at least 50 galls and then mixed to form one bulked collection. Inoculation was started on May 13, 1987, by blowing spores over the seedlings using an airsprayer adapted from an Erlenmeyer flask. Each replication was inoculated separately with a spore-to-seedling ratio of 20,000 to 1. The seedlings were kept in the mist chamber for an additional 72 hours in a visible fog. The mist nozzles were then turned off and the seedlings allowed to slowly dry for a day, then moved to a shadehouse.

After a few weeks of acclimation, they were moved to a nursery at Priest River Experimental Forest (48°21' N., 116°52' W., elevation 732 m) and planted at a 15- by 15-cm spacing in nursery beds 76 cm wide. The 10 seedlings for each population in each of the tree replications were planted in two adjacent rows of five trees each. Planting date was June 9, 1987.

Inspections for symptoms of infection were made for each seedling at 12 months and 27 months after inoculation. Data were tallied for the presence of galls and reactions on the stem indicative of defense reactions. The following variables were used to assess variation among populations:

1. Infected—trees with galls at 27 months.
2. Number of galls per tree.
3. Rust-killed trees—infected trees that died by 27 months.
4. Resistance—trees with no galls at 27 months. These were placed into three categories:
   a. No reactions. Trees that did not have galls or reactions in the stem that would indicate a resistance reaction.
   b. Bark reactions. Trees that did not have galls but that had a visible reaction in the stem.
   c. Gall death. Trees that had galls at 12 months after inoculation for which the gall was dead at 27 months.

Analysis of variance using SAS (1982) was completed to determine significant differences among stands; the analysis used plot means. Stepwise multiple regression models were used to relate rust variables to elevation and geographic location of the seed source. The independent variables were elevation, latitude, longitude, northwest departure, southwest departure, and distance from the inoculum source. Northwest (latitude x longitude) and southwest (1/latitude x longitude) departures were derived by rotation of the grid of latitude and longitude by 45 degrees. Squares of the above independent variables were added to accommodate the possibility of nonlinear patterns of variation. Therefore, 12 independent variables were included in a stepwise regression for maximizing R^2 (SAS 1982). In addition, the geographic variables were nested within four geographic regions: (A) northeastern Washington including Idaho north of Sandpoint and northwestern Montana north of the Kootenai River—a relatively wet area; (B) north-central Idaho from Sandpoint to Winchester—a somewhat drier area; (C) central to southern Idaho, from Winchester to the Idaho-Utah border—a fairly dry area; (D) western Montana, south of the Kootenai River and west of the Continental Divide—a relatively dry area (fig. 1).

RESULTS

The analyses detected differences among populations for all variables except for gall death (table 1). Most rust factors varied randomly with the environment; only the number of galls were related to elevation or geographic origin of the seed.

The average level of trees with galls 27 months after inoculation was 87 percent; populations varied from 45 to 100 percent (table 1 and fig. 2). The average number of galls was 3.28; this varied from 0.72 to 6.33 for populations (table 1 and fig. 3). The average level of dead infected trees was 21 percent, which varied from 0 to 58 percent for populations (table 1 and fig. 4). Three major categories of resistance were evident (table 1):

1. Trees that expressed no symptoms—8 percent. This varied from 0 to 48 percent for populations.
2. Trees that expressed stem reactions—4 percent. This varied from 0 to 41 percent for populations.
3. Trees in which the galls died—1 percent. This varied from 0 to 7 percent for populations.

Using all environmental factors with the average number of galls for populations, the R^2 for the best-fit multiple regression model was 0.54. Table 2 shows the significance of each of the environmental variables in the final regression model.

Figure 5 shows predicted values at a constant elevation (average elevation for all stands). The lines contact equal predicted values. The distance between contour lines equals ½[lsd(0.2)]. Thus, distance equivalent

Table 1—Means, range, and mean squares of symptoms of infection among provenances of lodgepole pine 27 months after artificial inoculation with western gall rust

Symptom of infection	Analysis of variance					
	x	Range	df	MS	F	PR>F
Infected (trees with galls)(percent)	87	45-100	106	0.4562	2.82	0.005
Number of galls	3.28	0.72-6.33	106	43.73	5.64	.005
Rust-killed trees (percent)	21	0-58	106	.4795	1.56	.005
Resistance (percent)	13	0-55	106	.4562	2.82	.005
No galls or reactions	8	0-48	106	.3053	2.20	.005
Bark reactions only	4	0-41	106	.1859	6.65	.005
Gall death	1	0-7	106	.0096	1.02	NS

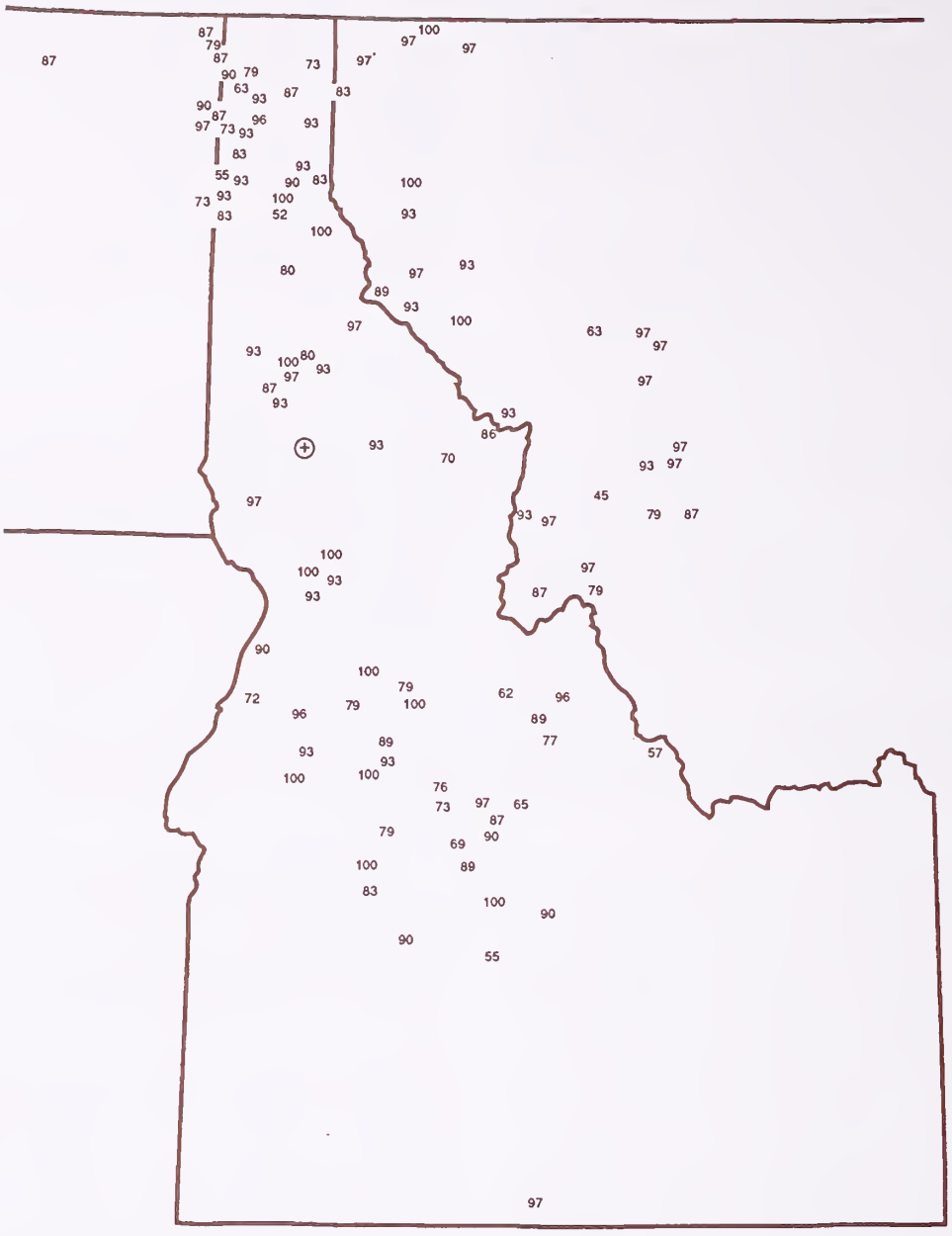

Figure 2—Level of infection of populations of lodgepole pine to gall rust. Numbers represent actual percentage of trees with galls for each population. Circled + represents inoculation source.

to two contour lines differs by a probability of about 0.2. From the point of origin of the inoculum (at the star), number of galls decreases to the northwest and slightly to the east, but the number increases to the northeast and remains about the same to the south except for the population at the border of Idaho and Utah, which has a higher number of galls.

Figure 6 shows the association between elevation of the seed source and the number of galls. The elevation cline is superimposed on a plot of the actual number of galls per population. It indicates that the number of galls decreases as elevation of seed source increases.

DISCUSSION

The general level of susceptibility of lodgepole pine to western gall rust was high. Nonetheless, some populations had quite high resistance. This resistance could be broken down into three major categories. The first included trees that had no obvious symptoms. These trees had either escaped inoculation, which

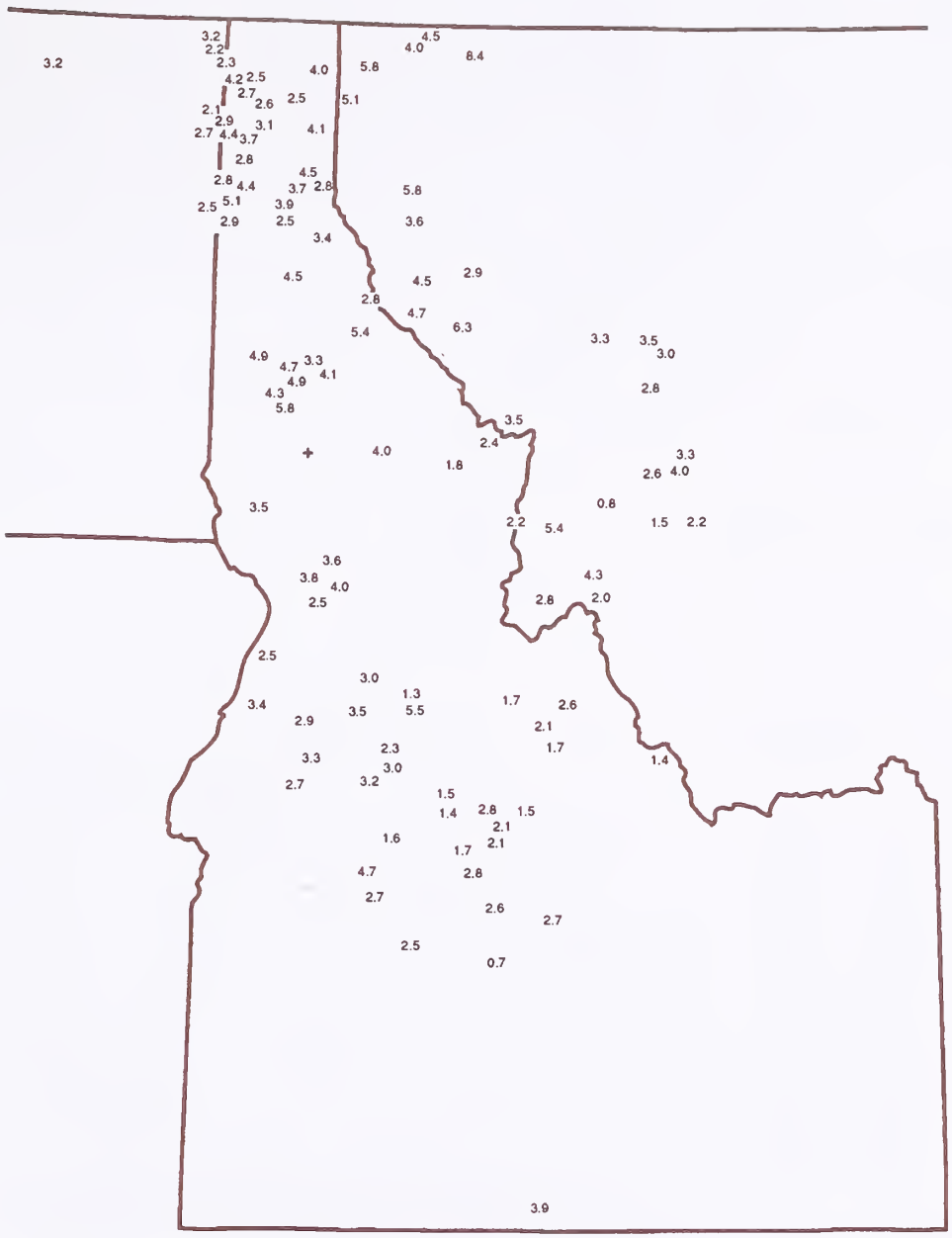

Figure 3—Average number of galls of western gall rust per population of lodgepole pine.

seems unlikely because of the high level of infection, or they had resistance mechanisms that prevented initial penetration or extensive fungal growth after penetration.

The second resistance category is a group of reactions in the stem that have prevented the fungus from becoming established. These reactions are recognized as necrotic patches of different sizes on the stem that have resulted in early fungal death. They first become visible within a few weeks of inoculation and continue to show up for 18 months.

The third category is the result of the death of what appeared to be a normal gall in a previous rust inspection. This is possibly an extension of the bark necrosis type of resistance. But because there was an obvious gall formation, and sometimes a rather large gall, I put these into a separate category.

All traits except number of galls varied randomly with elevation and the geographic origin of the seed. However, number of galls exhibited a weak relationship with geography and a slightly stronger relationship with elevation. Populations from the northwestern portion of the collection area had fewest galls, and populations from the northeastern and southern had the most galls. Gall number decreased with increase in elevation. Populations near the origin of the

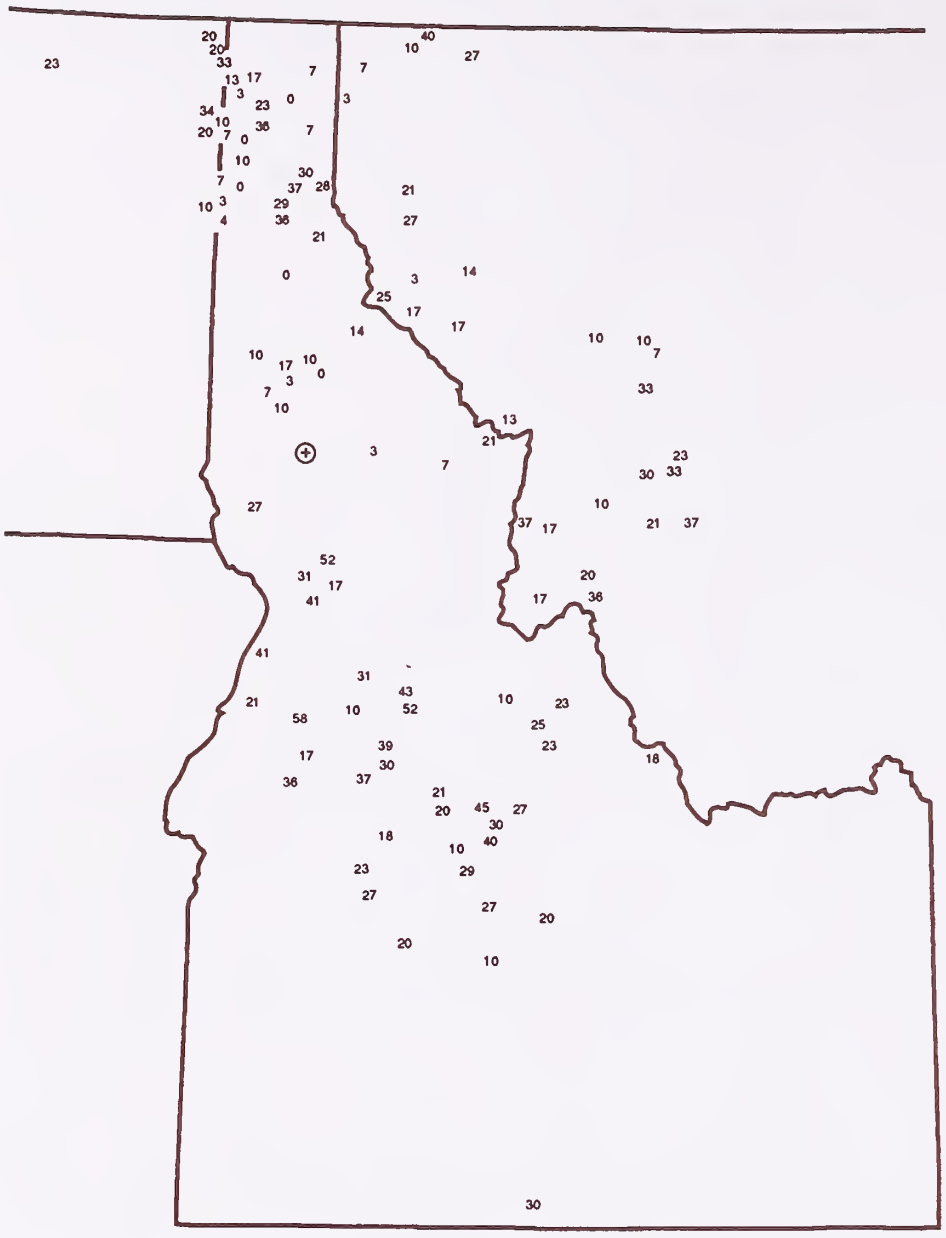

Figure 4—Percentage of seedlings that were infected with western gall rust that had died.

Table 2—Intercept and regression coefficients from the best fit multiple regression equation for infection of lodgepole pine by western gall rust

Factor	*b* value	Probability > *T*
Intercept	−2,948.32890	0.03
Elevation	−.00047	.0001
Latitude²	1.55886	.01
Longitude²	.24535	.02
Northwest	1.23958	.01
Southwest	2,354.46354	.03
Southwest²	− 466.68431	.03
Distance	−.03502	.002
Distance²	.00014	.0789

inoculum had relatively high susceptibility, which has previously been noted for loblolly pine and fusiform rust (Powers and Matthews 1980) and ponderosa pine and western gall rust (Hoff 1990). The explanation extended is that local rusts have become slightly more virulent to the local pine populations. Possibly the rust always applies a slight selection pressure on the local pine but not so much as to cause an increase in resistance genes.

Although there is little or no systematic pattern to the susceptibility of lodgepole pine to western gall rust within this test, there certainly are populations that have lower susceptibility—that is, fairly high resistance including several possible resistance reactions. Forest managers and tree breeders probably

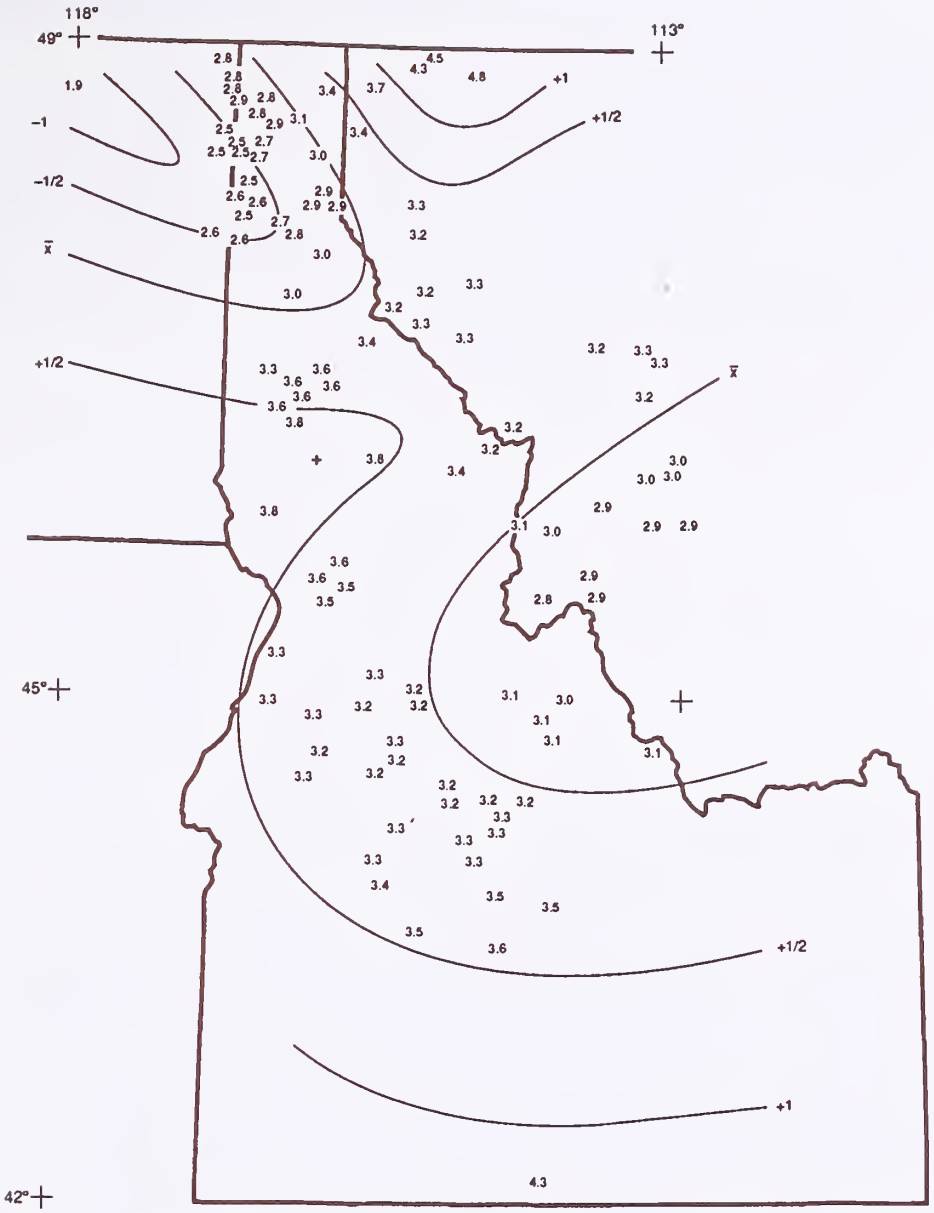

Figure 5—Number of galls of western gall rust per population of lodgepole pine. Numbers represent predicted values at the mean elevation of all populations (1,480 m). Contour lines represent lines of equal performance. The interval between contour lines equals ½[lsd(0.2)], and lines represent positive or negative deviations from the mean value of all populations.

should be cautious in transferring seed into areas where gall rust hazard is high, not in a general sense because of the lack of strong patterns, but in a specific sense because the level of resistance of a particular seed source cannot be predicted.

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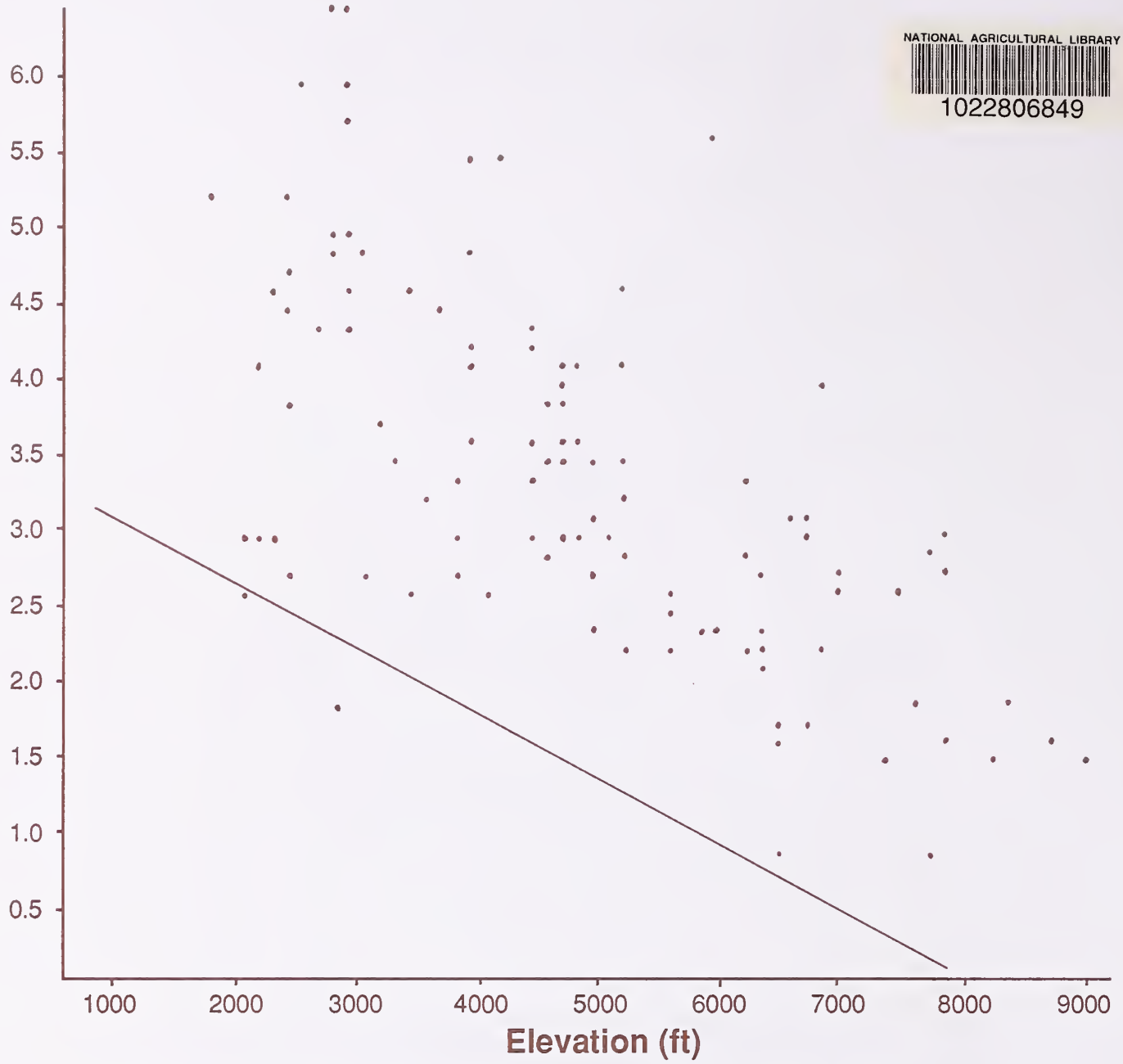

Figure 6—Actual percentage of infection plotted against elevations. Line represents predicted values.

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